# The transition from final-year high-school Physics and Mathematics to first-year Electrical Engineering: A work in progress

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***Abstract***: *The electrical engineering course ELECTENG 101, compulsory for all first-year engineering students at the University of Auckland, is perceived as "difficult". Pass rates have not been as high as in other year-one courses, particularly for under-represented groups such as Maori and Pacifica and women students. There is a perception that the modular teaching and assessment of the national high-school qualification has not prepared students well for study in this course.*

*This research study aims to identify the level of preparedness the year-one cohort brings to ELECTENG 101, to determine key factors that lead to success in this course, to measure the effectiveness of remedial and support mechanisms, and to audit the content and assessment of the course itself.*

*A two-cycle action-research methodology is proposed. This paper presents results obtained from the delivery of a diagnostic assessment in the first week of the 2007 class and subsequent interviews with class members.*

## Introduction

A potential mismatch exists between the increase in the number of engineering graduates demanded by industry (Cleland, 2007) and the decrease in the number of final-year high-school students studying physics and other engineering-specific pre-requisite subjects. It is recognised that if the engineering faculty is to respond to industry calls for an increased number of engineering graduates, it is probable that a large portion of that increase will come from a more diverse range of students, possibly with lower entry levels in mathematics and physics than in previous years. It is also recognised that while these students may initially struggle academically they have the potential and motivation to make a significant contribution to the engineering profession provided appropriate academic support systems, remedial and "catch-up" courses, and social integration are provided.

The overall goal of the research project is to maximise the achievement of the students enrolled in the compulsory first-year electrical engineering course, "Electrical and Digital Systems" (ELECTENG 101). It is essential to identify the academic preparedness of students for their first-year studies to enable the curriculum, assessment and teaching methods to respond effectively, but new and more diverse entry qualifications introduced over the last few years have made this identification task much more difficult.

Whilst there is a need for the first-year experience for the BE to be examined as a whole, the course ELECTENG 101 provides a particularly good starting point for such an analysis because its pre-requisite knowledge and skills can be clearly articulated.

This study will not only provide a wealth of data and recommendations that may be used to lift the achievement of students enrolled in ELECTENG 101 but will also provide a model for examining other first-year courses and the first-year experience as a whole. Success and retention at first year is crucial if the number of graduates is to increase.

Both quantitative and qualitative data will be collected. Quantitative data, such as academic background and university assessment data, will be analysed and interpreted using standard statistical software. In-depth qualitative data will be collected via semi-structured interviews and surveys from high-school students and their teachers, as well as from university students, their lecturers and tutors, to enable the study to “drill down” into the quantitative results and to illuminate conceptual understandings and misunderstandings as well as perceived barriers to the achievement of the desired learning outcomes.

Specific objectives include:

- To analyse the educational background of the students in ELECTENG 101, particularly relating to physics. Subject data is available for students entering with National Certificate of Educational Achievement (NCEA - details available at http://www.nzqa.govt.nz/ncea/), Cambridge International Examination (CIE - details available at http://www.cie.org.uk/) or International Baccalaureate (IB - details available at http://www.ibo.org/) qualifications. However, other background aspects such as exposure to practical laboratory work and the extent of the students’ mastery of physics concepts are also likely to be important to the students’ ability to apply theoretical knowledge in engineering-related study.
- To determine the educational achievement and learning outcomes of the students in ELECTENG 101. Analysis of assignment, test and examination results will be supplemented with semi-structured interviews to reveal the “how” and “why” of this achievement.
- To search for patterns and correlations between the high-school educational backgrounds of the students, the results of diagnostic tests measuring concept mastery, and their year-one achievements.
- To pursue two cycles of action research in which the effects of changes implemented after the first cycle are investigated.
- To set precedents for methodology and data analysis that will contribute to the wider analysis of the first-year experience in engineering. It is envisaged that the findings from this research will inform appropriate modifications to other first-year engineering courses, and the initiation of targeted “catch-up” courses and ongoing support where appropriate.

## Proposed Research Project

The overall goal and the associated specific objectives are as stated above.

An action-research methodology (Riding, 1995) has been chosen because the aim is not only to investigate the transition from high school to university but also to improve the situation of the students making the transition. Improvements can be expected over the iterative cycles of investigation and analysis, planning and action, and evaluation and reflection.

The initial phase of the research project has three main parts to it. The first is a review of the relevant literature. The second is an investigation into the educational background of the students in the year-one electrical engineering course. The third is an investigation into the educational achievement of the students in the year-one electrical engineering course.

Part of the investigation into the educational background of the students will entail an analysis of their examination results. For example, in the case of those students who sat the NCEA Level Three examinations, this will involve determining which achievement standards they achieved, their grades in these standards, and the overall national distribution of grades in the standards year-by-year. Similar sorts of analyses will be carried out for those students who sat the CIE or the IB. Diagnostic tests will also be used to further investigate the students’ educational background. The OASIS software package

(Smaill, 2005 - 2007) is likely to play a key role in delivering, marking and analysing these diagnostic tests.

As outlined above, a schedule of interviews with students and staff at both high school and university will elicit the meaning and understandings that students have in relation to their study, the subject itself and concepts within the subject. It is also hoped that perceived barriers will be identified by this methodology. It is intended that interviews with current students be conducted by an experienced qualitative researcher, to allow students to respond in an anonymous and unbiased manner.

Similarly, examination and test results, together with interviews and surveys, will be used to illuminate the educational achievement of the students in the year-one electrical engineering course. The interviews and surveys will be particularly useful for gaining an insight into student perceptions of their educational experiences as they move from high school to university. Teacher and instructor perceptions will also form an important part of this study. All the above will be supplemented by published research that has already been carried out. However, although there is considerable literature now relating to the school-university transition (for example, Macdonald (2000)), there is little published literature that is directly relevant to the effects of new qualifications such as NCEA on tertiary preparedness in courses where subject-specific knowledge is assumed.

The analysis of the collected data will proceed on several fronts. Correlations between NCEA achievement-standard grades and year-one BE examination results, for example, can be determined using the software package SPSS (details available at http://www.spss.com/spss/). The number of variables is extremely high and a degree of professional judgment will be needed to determine which possible patterns and correlations merit further investigation. For example, is type of school or educational background of the high-school teachers relevant? It may even be that rather intangible variables such as interest in engineering or determination to succeed are as important as prior examination achievement.

To a large extent, modifications to the action-research programme will follow naturally from the findings of the above analyses. Some clear weaknesses can be directly addressed through changes to the course content and delivery: for example a subject-based weakness such as a lack of basic electric-circuit theory. Other weaknesses, such as a lack of self-confidence or a failure to see the relevance of the course being studied, may require more specialised external input. Extreme subject-based weaknesses may also require specialised external input, perhaps in the form of remedial courses.

Findings from this study may also impact on selection criteria for entry to engineering, or lead to a recommendation for alternate pathways via remedial courses.

More than one cycle of the research programme will certainly be necessary. For this reason the research programme will run over at least two years. Further, this study, focused on just a single year-one course, is ideally placed as a pilot study for an action-research programme aimed at raising the academic achievement of the year-one students in all their courses. Certainly, one of the objectives of this research programme is to make recommendations aimed at enhancing educational outcomes in all year-one engineering courses

## Students' Educational Background

As a first step in gathering information about the student's educational background, a diagnostic assessment was administered at the start of the ELECTENG 101 course. This 30-minute assessment consisted of 22 questions. The first 20 questions were multiple-choice while the final 2 questions were free-response questions. The 20 multiple-choice questions (worth 1 mark each) covered simple circuit theory (involving batteries, switches, light bulbs and resistors), forces exerted on charges and currents in magnetic fields, and electromagnetic induction. The first free-response question addressed simple circuit analysis (worth 3 marks) while the second addressed simple algebraic manipulation (worth 2 marks). These two free-response questions were marked either right (full marks) or wrong (zero marks).

560 students completed the 22 question test. The test invigilators reported that the 30 minutes allocated to the test appeared to be ample, as a significant number of students appeared to finish with

adequate time to spare. The students also appeared to take the test seriously, as evidenced by the fact that they did spend most of the allocated 30 minutes working on their answers, and by the amount they wrote in answering the free-response questions. A mark histogram is provided in Figure 1.

The average mark was 10.4 out of 25. A student who answered all the multiple-choice questions randomly and scored zero on the remaining two (free-response) questions would expect a score of 4.6. However, an analysis of the test results revealed that 31 students (5.6%) actually scored 4 or under, while 55 students (9.8%) scored 5 or under.

At the upper end of the class, only 30.2% scored 13 or more on the test, with a mere 6.6% scoring 20 or more on the test. Only one student scored 25, none 24, and one 23.

For the 20 multiple-choice questions (Q1-Q20) the average was about 9 out of 20. In the case of the free-response questions, Q21 (year-12 electric circuit theory) was correctly answered by only 11% of the students, while Q22 (year-11 mathematics) was correctly answered by 60% of the students. Here it should be noted that year-13 is the final year of high-school education in New Zealand.

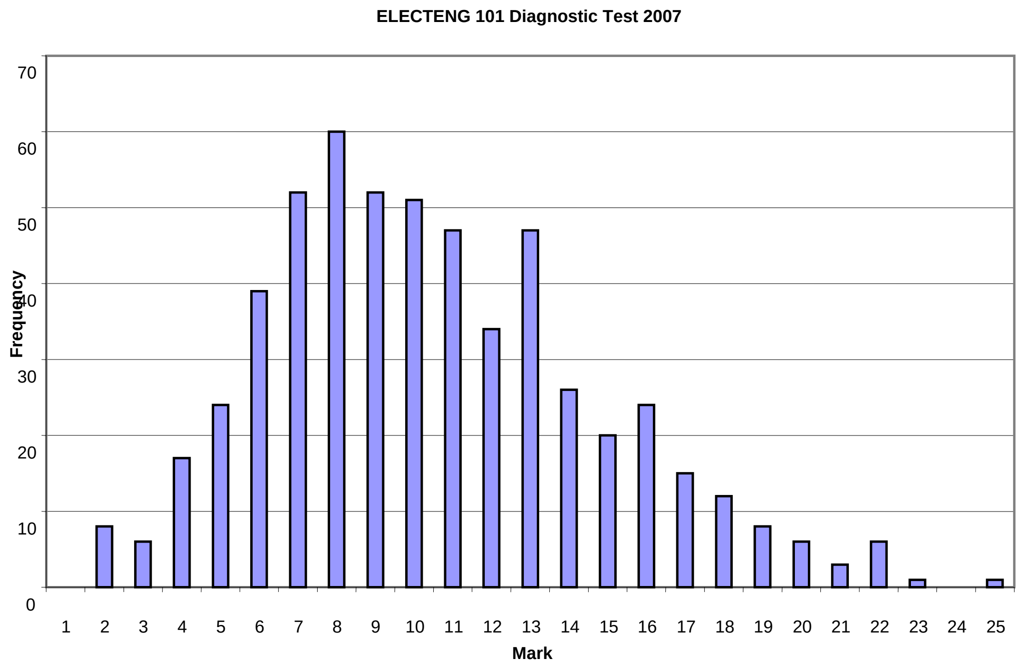


**Figure 1 Mark Histogram for 2007 Diagnostic Test**

The results were clearly very disappointing. They appear to indicate that most of the class either had not understood or had forgotten most of the basic physics they covered in high school. To enable better interpretation of these results, a number of class members were interviewed in either focus-group sessions or individual interviews, during weeks five and six of the semester. The interviews were conducted by one of the authors (who was not involved in teaching the class and was unknown to the students). The interviews used the diagnostic test as a basis and largely consisted of open-ended questions that asked the students to explain their thinking processes in answering the various questions. The interviews were audio-recorded, with these recordings being used to supplement notes taken by the interviewer.

When students sit a diagnostic test, the score for which has no effect on their class grade, it is inevitable that some fraction will devote little effort to answering the questions. When selecting students for interview we deliberately did not select any whose diagnostic test score was equal to or below the random guessing score of 4.6. This is consistent with the approach followed by Steif and Hansen (2007). Similarly, since we wished to probe conceptual misunderstandings, we chose not to interview students with diagnostic test scores of 14 or higher. The students invited to the interviews thus all scored marks in the range 5 to13 out of 25. The students were selected in such a way as to ensure an even spread over this mark range.

In the interviews, the students indicated the following:

- Sufficient time was allowed for the test.
- The class did make a genuine effort in answering the test questions. However, the students were not unduly troubled by their results as the test did not count toward their final course grade.
- The students were surprised at how much they had forgotten. They reported that many of their peers realised they had not done very well.
- There was little discussion of the test amongst the class subsequently, with discussion confined only to the hour or so immediately following the test.
- Two areas were identified as being particularly difficult, namely circuit theory and the use of “hand-rules” to work out the direction of forces in electromagnetics problems.
- Some students had been taught physics using electron flow rather than conventional current. Specific ad-hoc rules had often been taught in high schools for generators while other rules had been taught for motors. When asked to identify difficulties encountered in answering the diagnostic test, one student commented “...just trying to remember the hand rules - left hand and right hand. You just know left hand for electrons and right hand for current”. By contrast, the unified approach for motional electromotive force (emf) taught in ELECTENG 101 that used right-handed coordinate systems and conventional current were seen as preferable: “What we are learning now....everything in the right hand...it’s good to have that.”
- In trying to answer the questions, the students relied on recall of equations from high-school physics and, occasionally, recall of high-school laboratory experiments. They did not indicate that they used examples from the physical world to inform their answers. For example, in commenting on encountering difficulties with the circuit questions, one student noted: “I’d forgotten all of Kirchhoff’s laws. I couldn’t remember which one was current and which was voltage.” Another stated: “I couldn’t actually remember the current-divider rule.”
- The students commented on differences in topic coverage and depth of coverage across the various entrance qualifications of NCEA, CIE and IB. They saw this as an issue that might explain misconceptions students exhibited on parts of the diagnostic test.
- The students displayed a preference for the use of numbers rather than symbols when performing calculations.

Common areas where misconceptions were found included:

- The division of current through parallel paths in a circuit.
- A belief that a magnetic field could exert a force on a stationary electric charge.
- The determination of the direction of force on charges in a conductor moving across magnetic field lines.

Subsequent review of the interviewer’s notes and of the audio recordings highlighted a student learning approach that could best be described as “bitsy” rather than unified. A possible explanation for this approach is that the recent introduction of the achievement-standards-based NCEA qualification in New Zealand high schools has led to teachers adopting a more modular teaching style which, in turn, has encouraged students to adopt a more fragmented approach to their learning. When asked to offer explanations for the poor results obtained across the class, some interviewees commented that the diagnostic test (which occurred in week one of the second semester) had taken place nine months after they had last studied the topic of electricity. They felt that students had performed poorly simply because they had forgotten the material. Anecdotally, by the time of the interviews in weeks five and six of the semester, these same students demonstrated to the interviewer a far better understanding of the material than was exhibited in their diagnostic test performance. The implications of the above observation for the identification of the learning model used by first-year students are not yet clear, and we propose to continue to collect interview data while we endeavour to identify the learning model being followed.

## Conclusions

The methodology for a two-cycle action-research project investigating the high school to university transition for a particular electrical engineering course has been defined. A diagnostic test has been designed to gather information about the students' educational preparedness. This diagnostic assessment was administered in the first week of a year-one electrical engineering course. The results revealed that most of the students had serious misconceptions in entry-level tertiary physics. Interviews conducted in weeks five and six with a sample of this class identified variations in content and depth of coverage between the various entrance qualifications (NCEA, CIE and IB) as one problem. In addition, the modular assessment approach adopted by NCEA does appear to hinder an integrated understanding of subject matter. The use of ad-hoc rules for the treatment of physical phenomena (e.g. specific instances of motional emfs) also appears to be an impediment to learning. By contrast, the consistent unified approach taught at university was seen as preferable. Circuit theory and motional emf were identified in interviews as areas where misconceptions were pronounced. The next phase of the research will involve a detailed literature review, a review of NCEA / CIE / IB results and a review of the 2007 class's coursework and examination results.

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